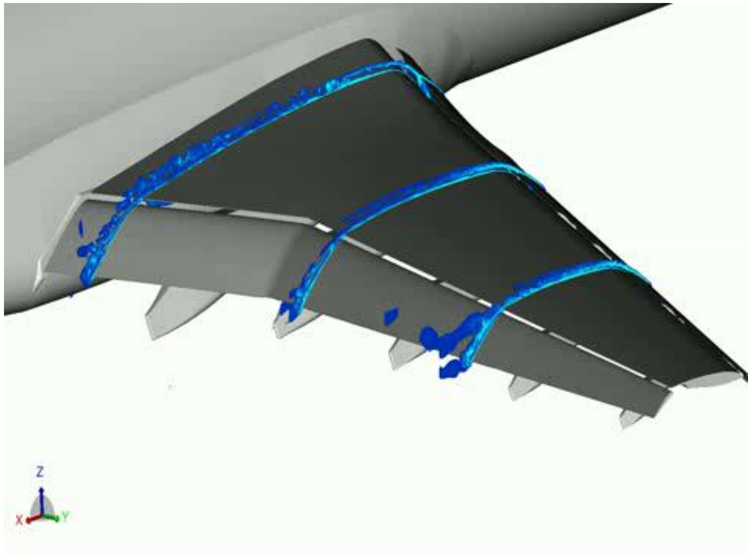

PowerFLOW Analysis
HiLiftPW-2 Configuration

AIAA SciTech 2014
National Harbor, Maryland

Benedikt König
Ehab Fares
Swen Nölting

Introduction
Geometry and Model

- Based on DLR-F11 landing configuration
  - *EUROLIFT project*
  - *Wing/body with full span slat/flap (26.5°/32°)*
  - *Slat tracks and flap track fairings included*

Content

- Introduction Lattice Boltzmann Method
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  - *Wind Tunnel Effect*
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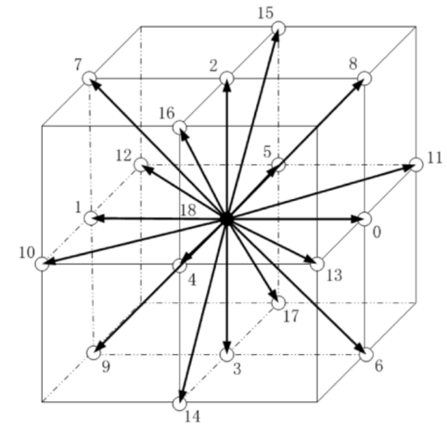
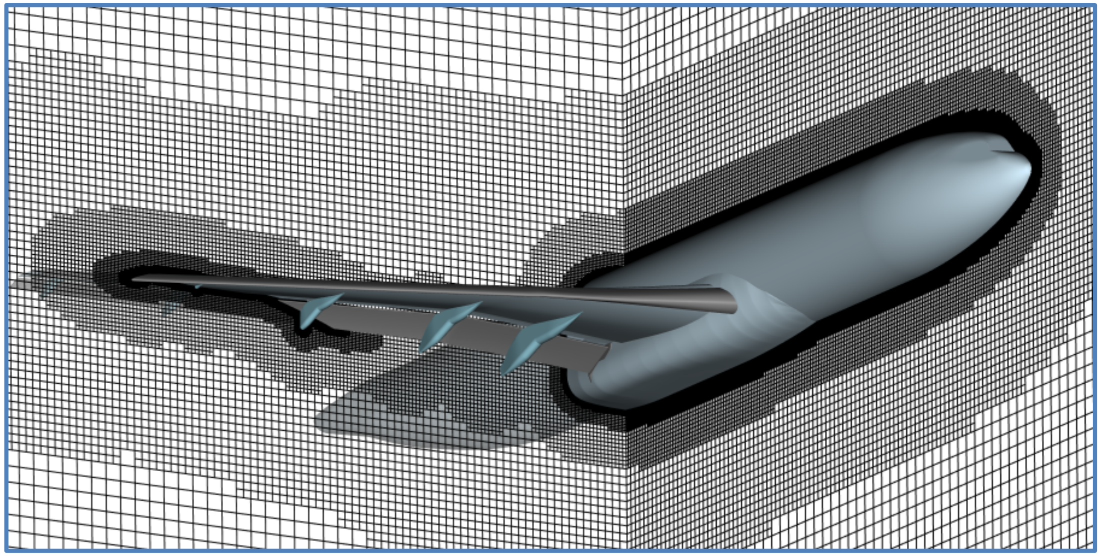
Lattice Boltzmann Method

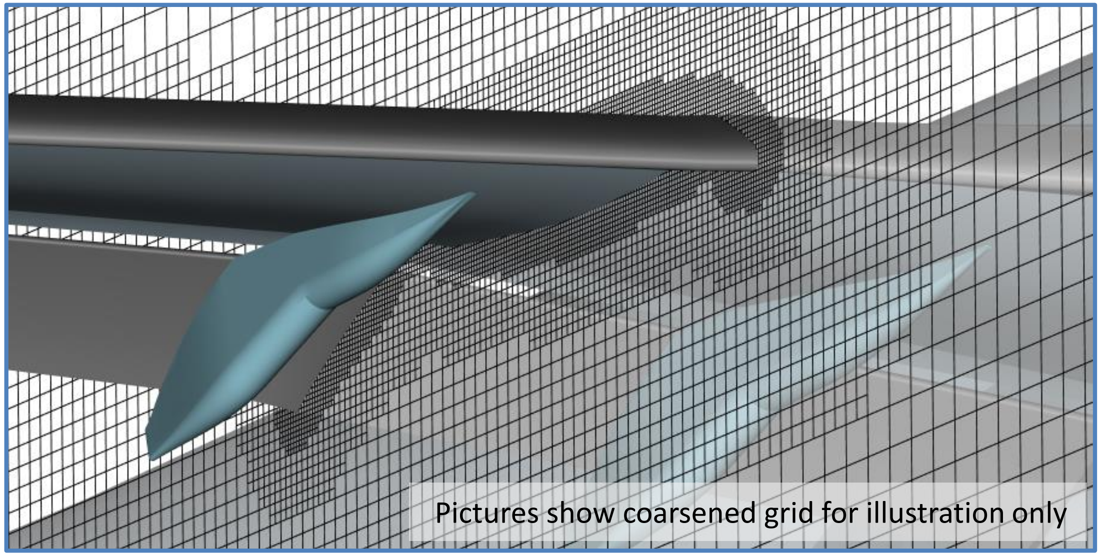
- Simulations performed with Lattice Boltzmann based solver PowerFLOW 5.0
  - *D3Q19 LBM*
    - Cubic cells (Voxels)
    - Surface elements (Surfels)
  - *Fully transient*
  - *Turbulence Model: LBM-VLES*
    - Modified RNG *k*-*ε* model for unresolved scales
    - Swirl model
    - Extended wall model
  - *LTT Model*
    - Automatically determines transition locations



Lattice Boltzmann Method
Grid Scheme

- Cartesian Grid
- Voxel/Surfel concept with cut cells
  → no surface fitted grid required
- Automatic and robust grid generation process





Case Sizes and Computation Resources

- Case sizes for low Reynolds number cases

Case	Total Voxels	FeVoxels
Free-air	405×10^6	100×10^6
Wind tunnel	470×10^6	110×10^6

- Compute Resources (free-air simulation)

Number of nodes	560
Architecture	Intel Sandybridge, 2.7GHz
Runtime to convergence (~0.15s)	20000 CPUh, 1.5d wall-clock time

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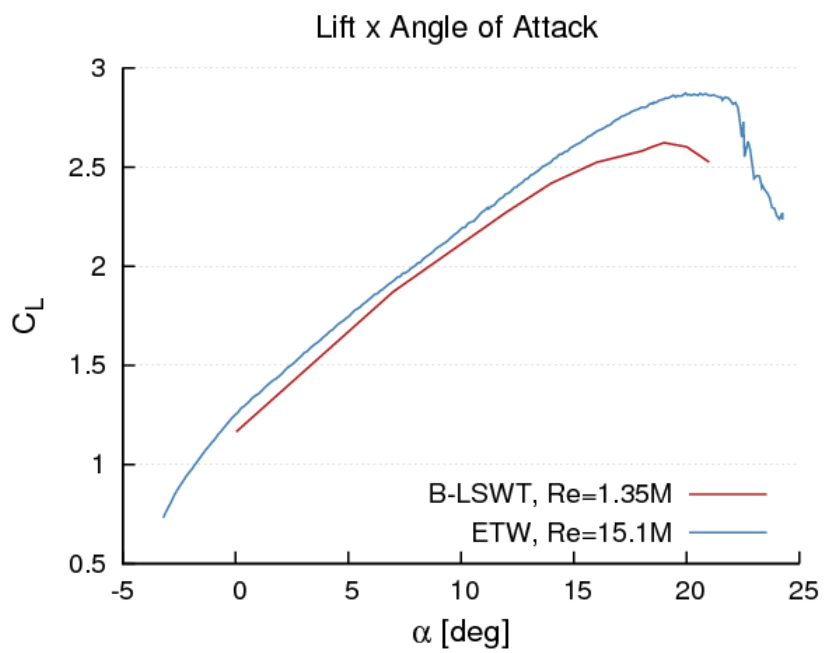
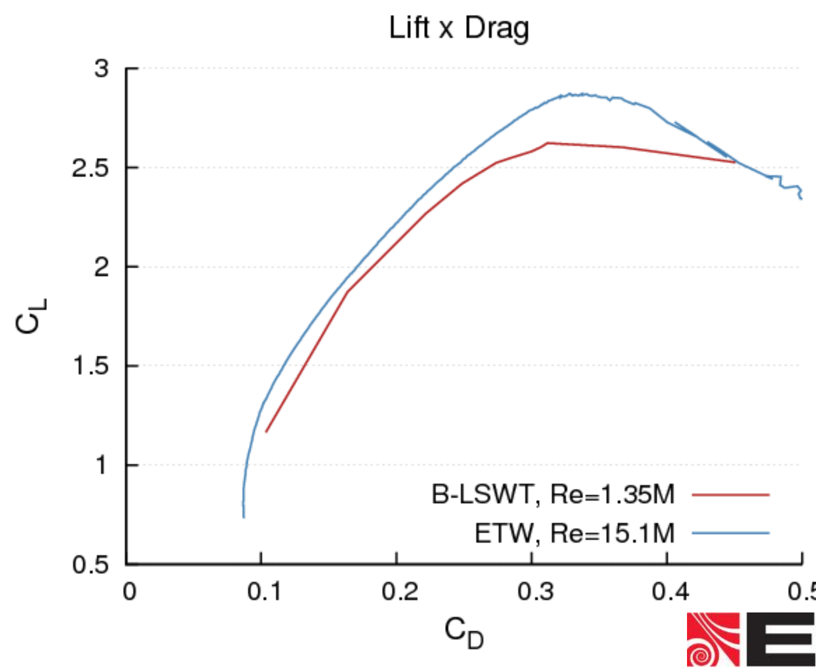
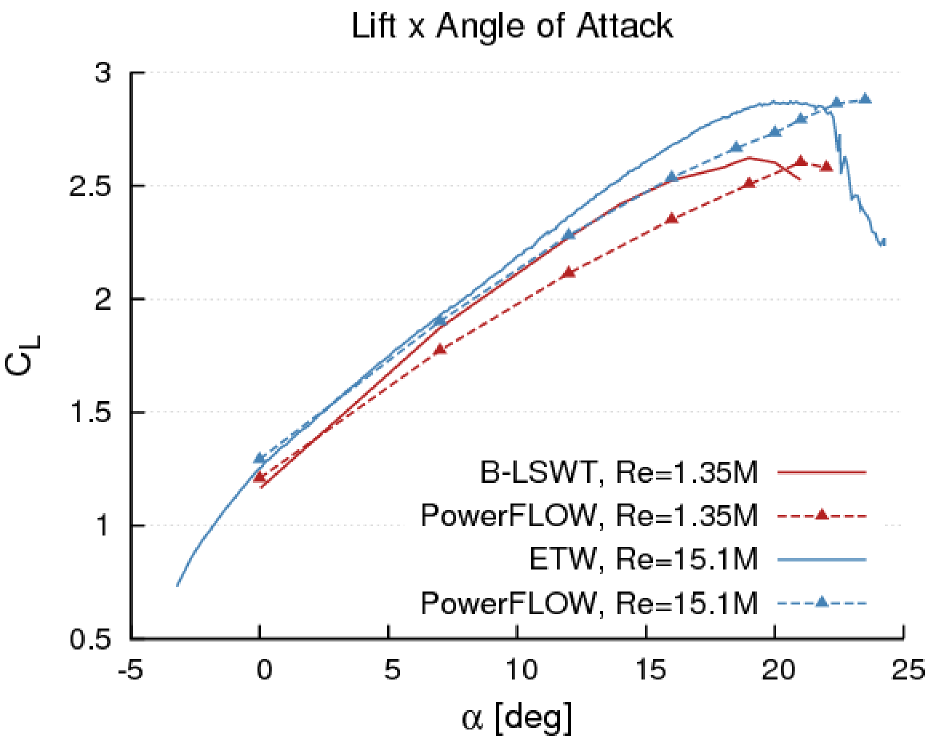
Reynolds Number Study
Introduction

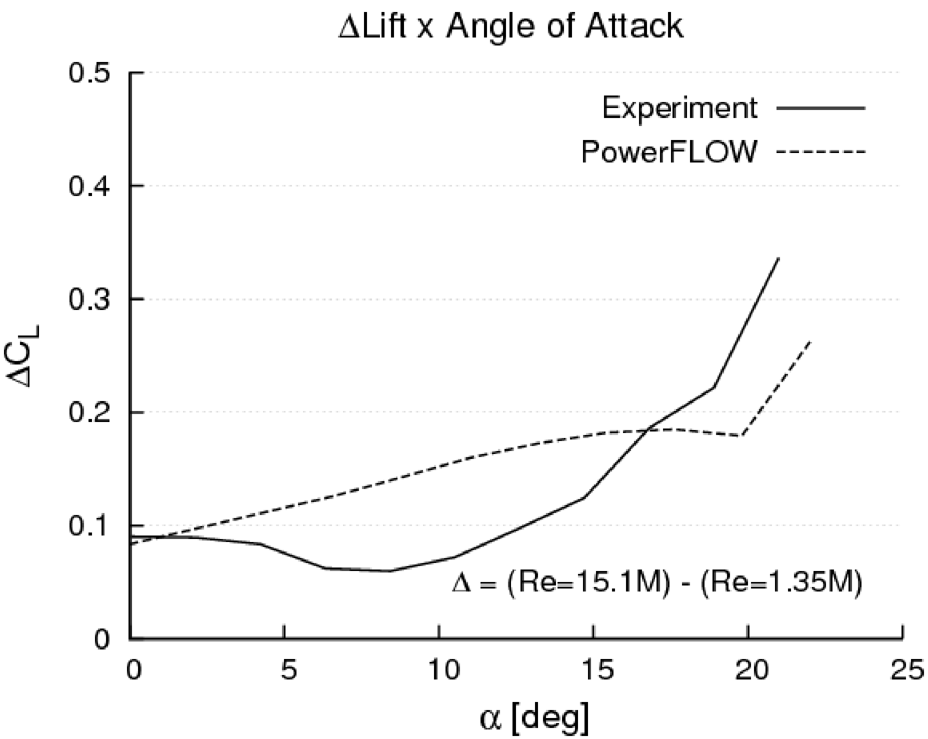
- Compare full polars at two Reynolds numbers
  - *$Re_{low} = 1.35 \times 10^6$ (B-LSWT)*
  - *$Re_{hi} = 15.1 \times 10^6$ (ETW)*
- Grids specific to each Reynolds number used





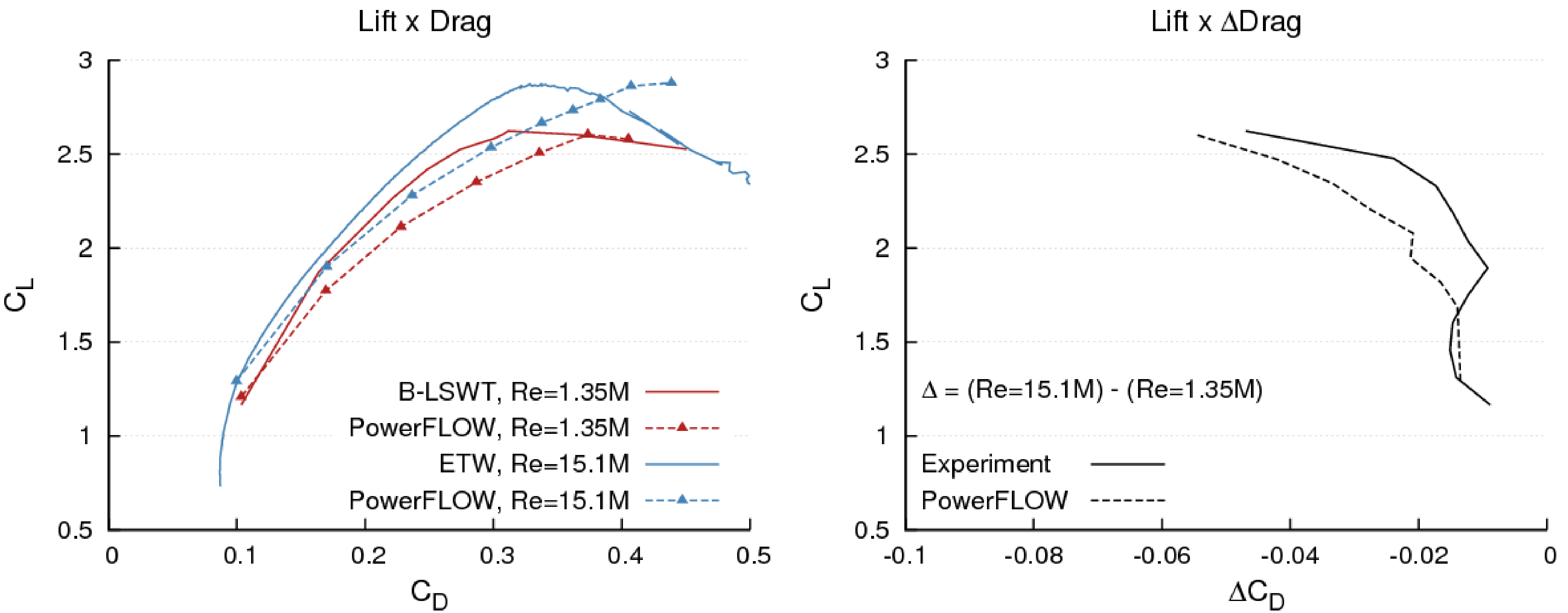
Reynolds Number Study
Lift Polar





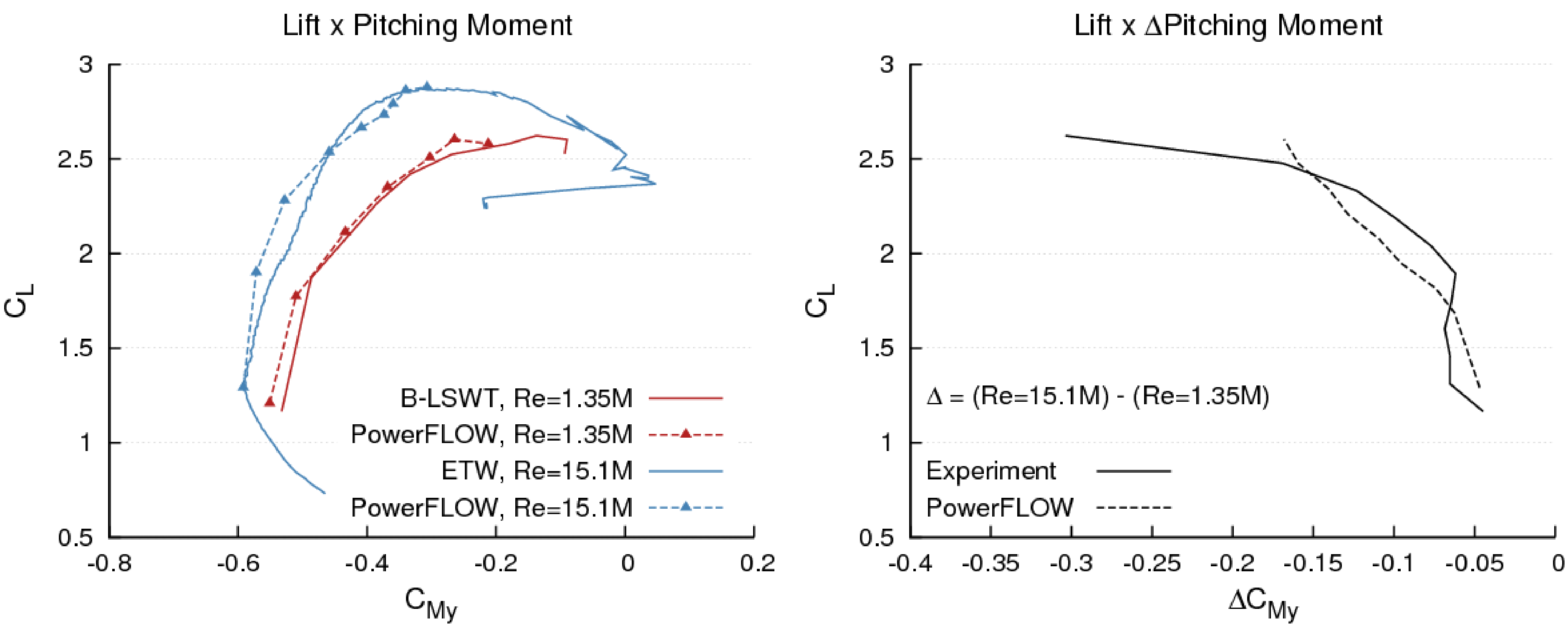
- $C_{L,max}$ well predicted for both Reynolds numbers
- Differences in lift slope and stall angle
- Reynolds trend captured well

Reynolds Number Study
Drag Polar



- Very good agreement at low C_L
- Increasing deviation at higher C_L / AoA
- Reynolds trend captured well

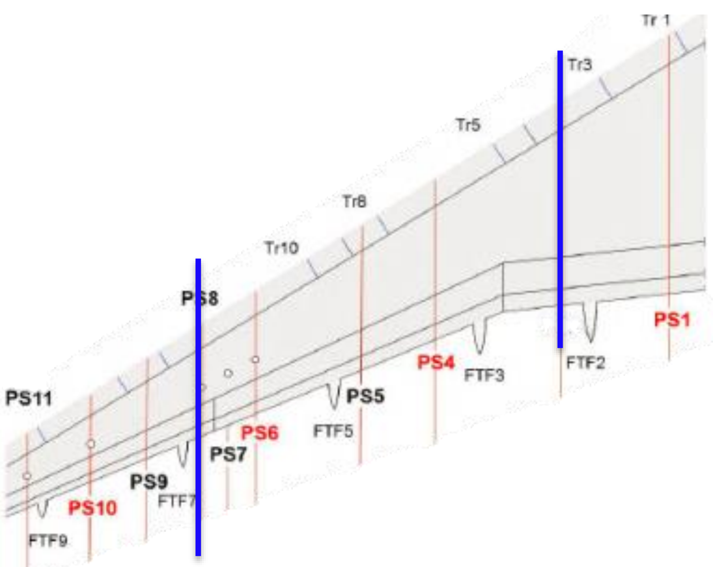
Reynolds Number Study
Pitching Moment Polar

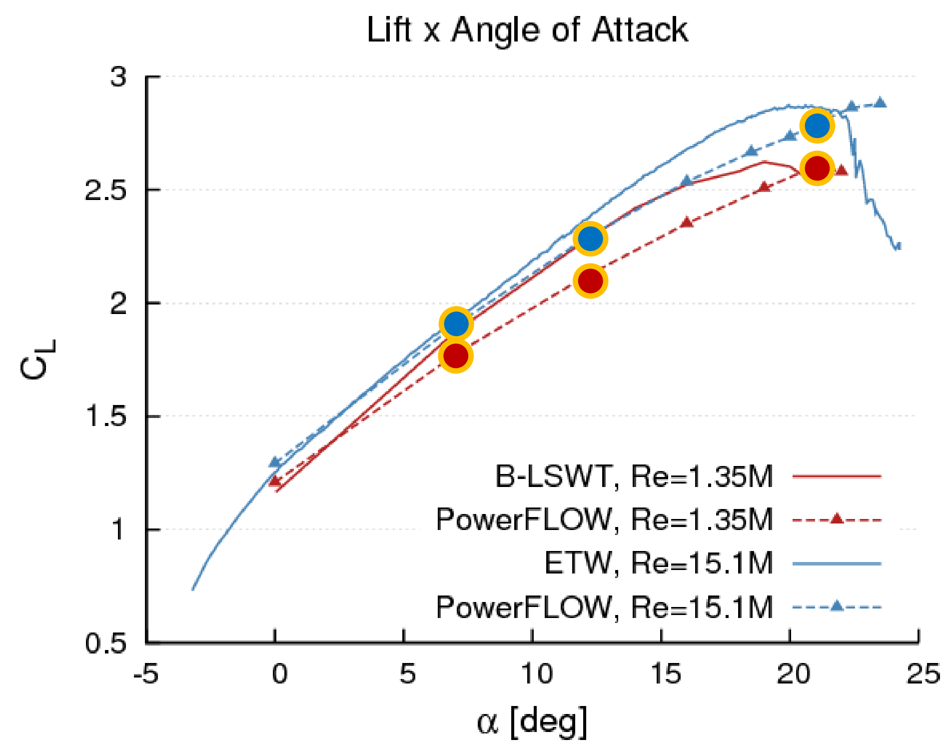


- Pitching moment very well captured
- Reynolds trend also captured well

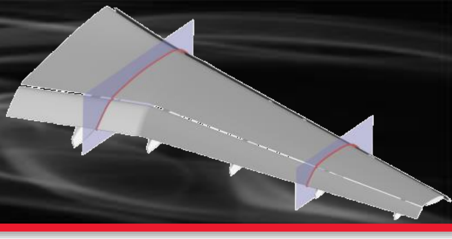
Reynolds Number Study
Pressure Distributions

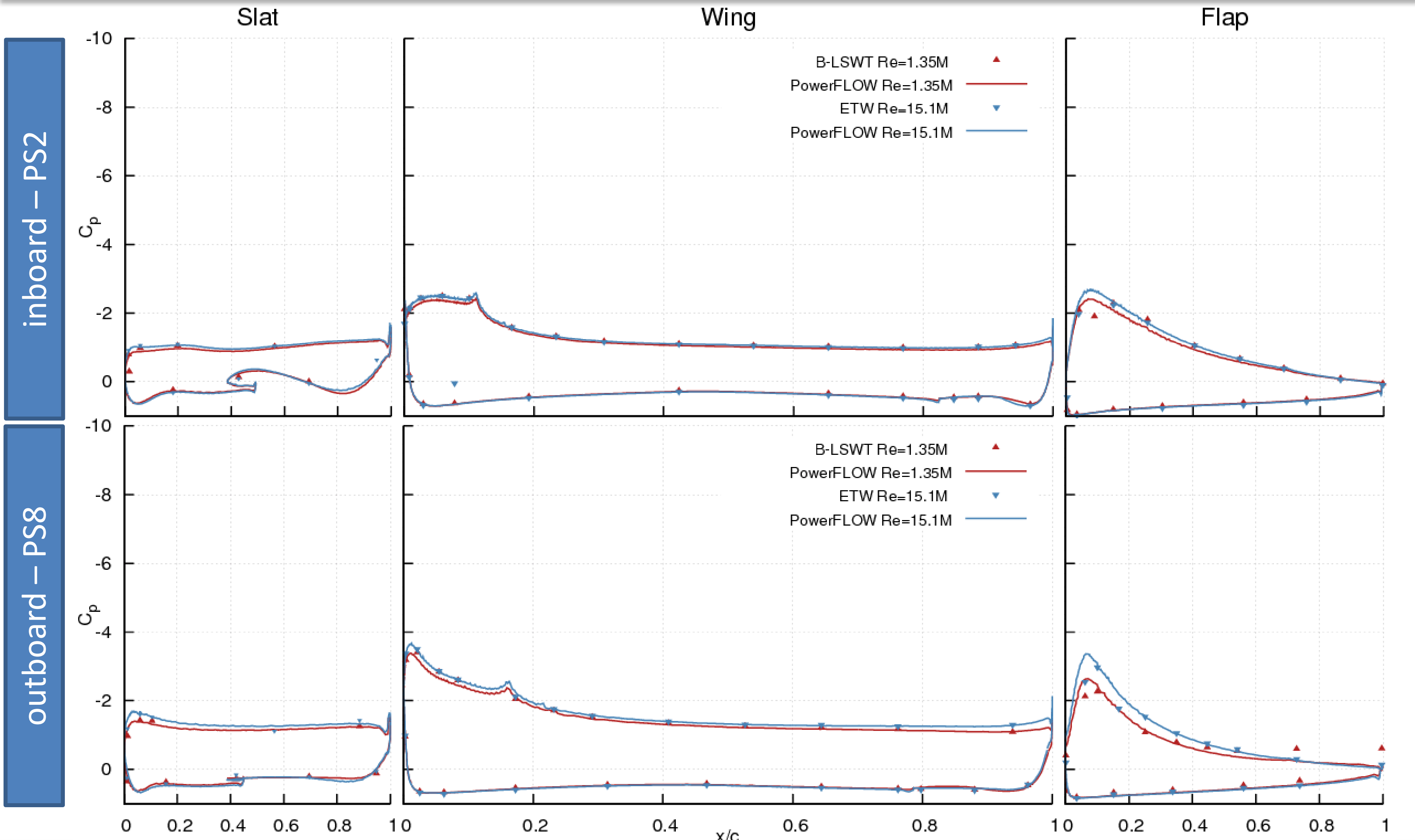
- Pressure distributions at Alpha= 7°,16°,21° are shown
- Inboard (PS02) and outboard (PS08) sections





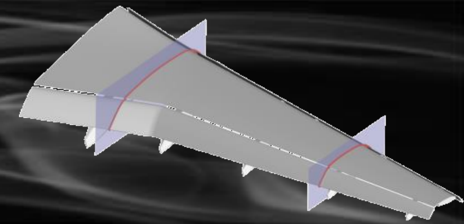
Reynolds Number Study
Pressure Distributions – Alpha = 7deg

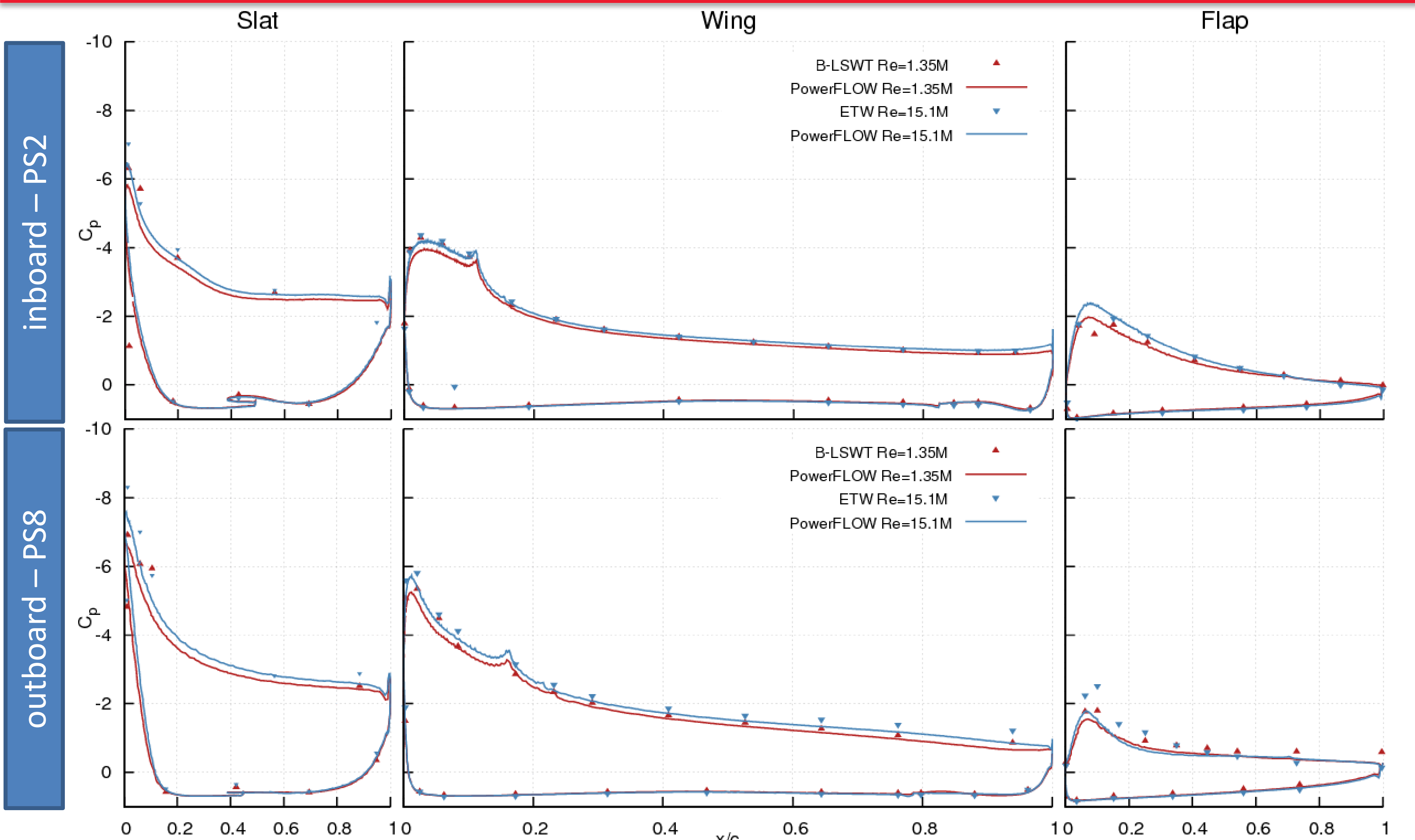




Reynolds Number Study

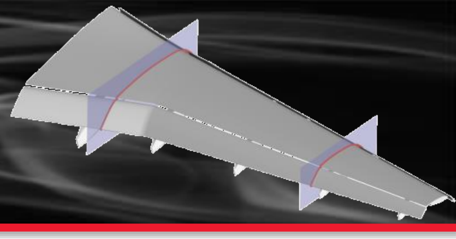
Pressure Distributions – Alpha = 16deg

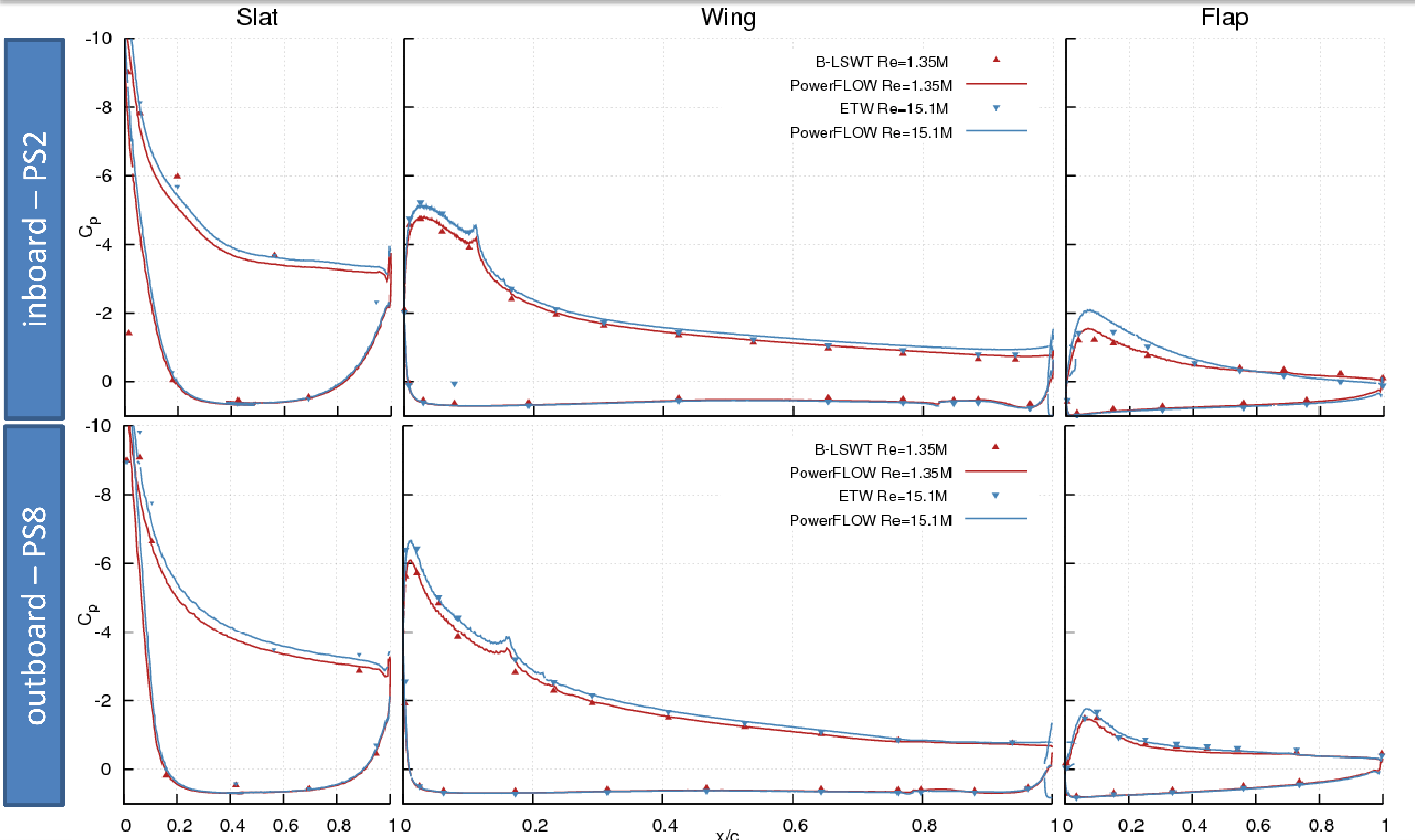




Reynolds Number Study

Pressure Distributions – Alpha = 21deg





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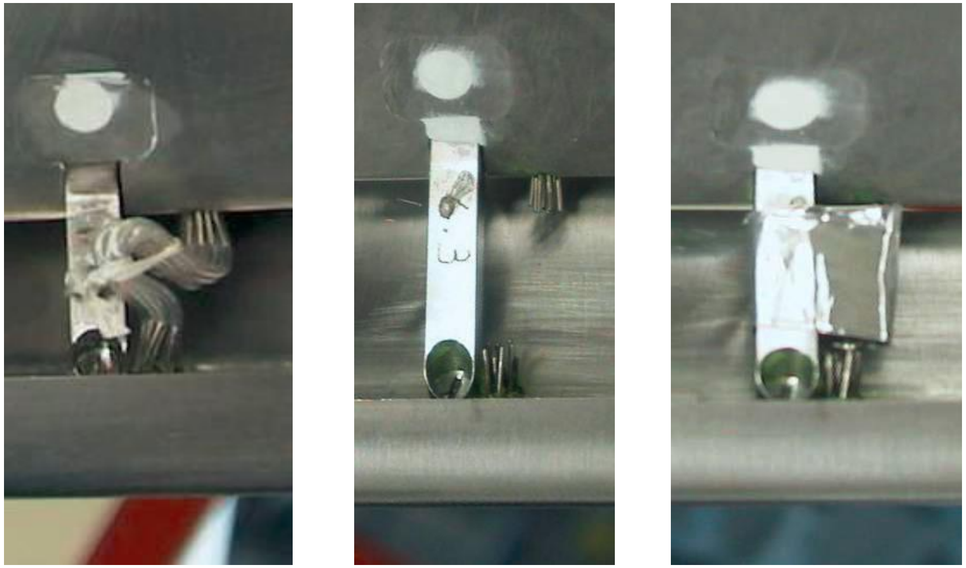
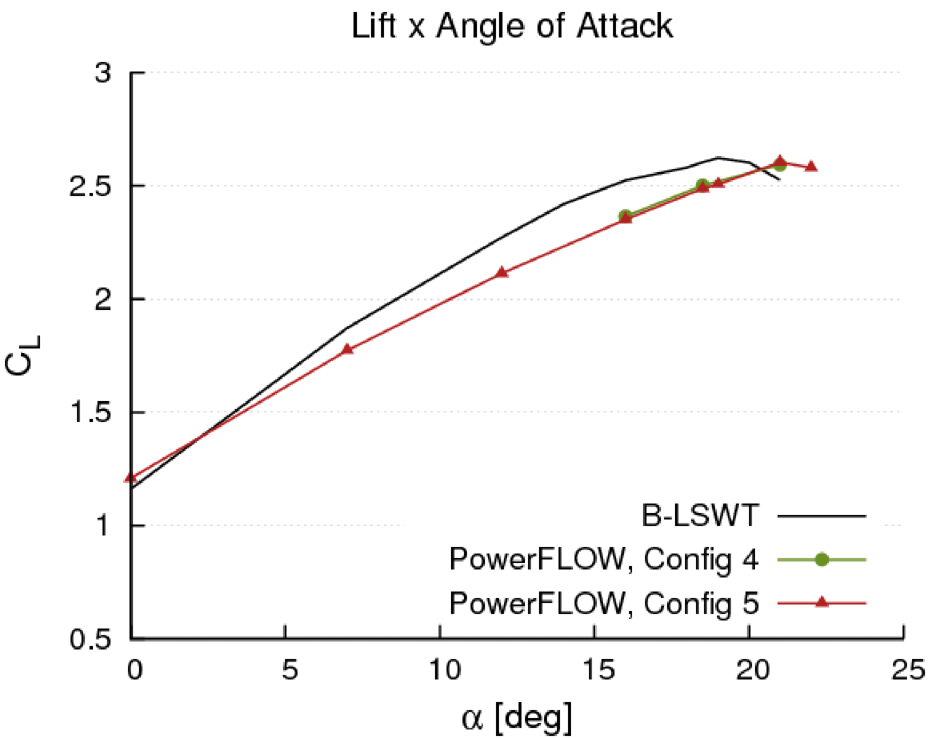
Full Configuration Study
Introduction

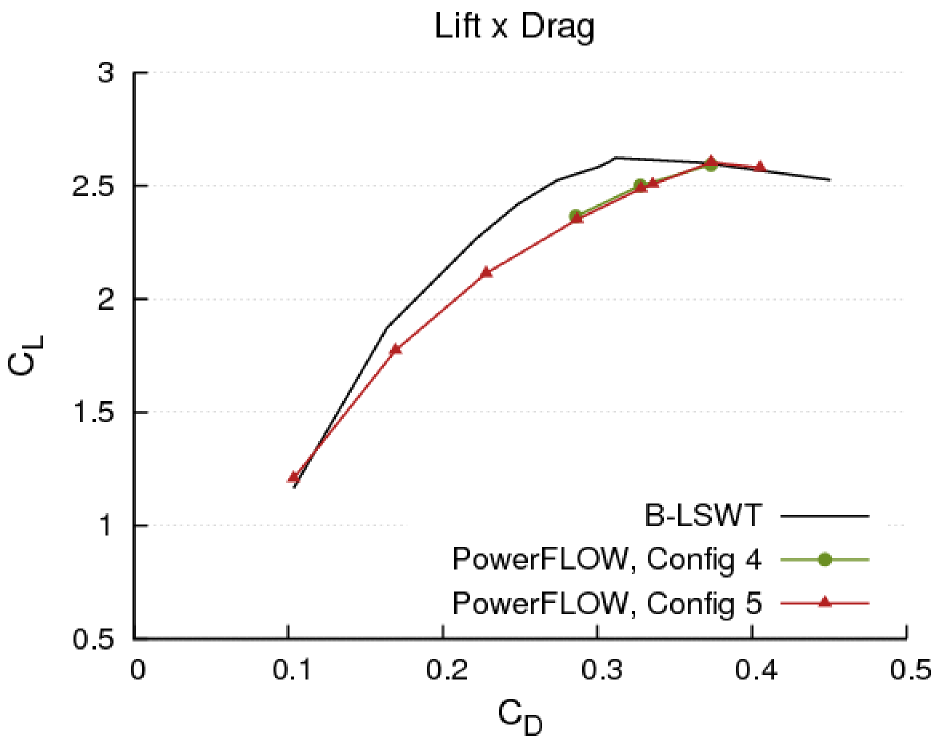
- Compare two levels of geometrical complexity
  - *Config 4 (w/o pressure tube bundles)*
  - *Config 5 (with pressure tube bundles)*
- Measurements at B-LSWT showed significant impact of these bundles on stall behavior



Photos taken from Rudnik et al.
AIAA 2012-2914

Full Configuration Study
Lift Polar



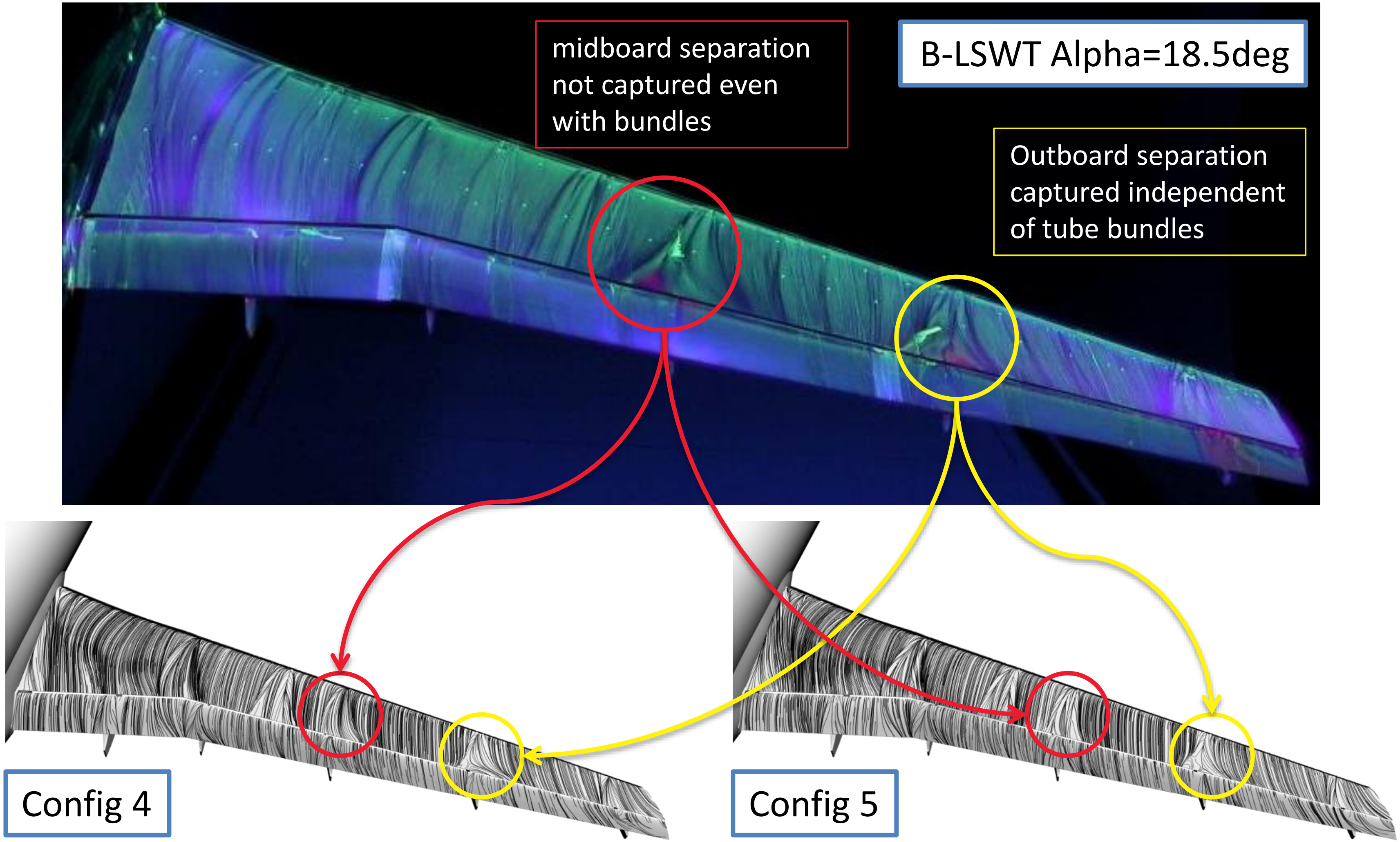


- Basically identical forces
- Presence of the bundles has no significant impact on forces

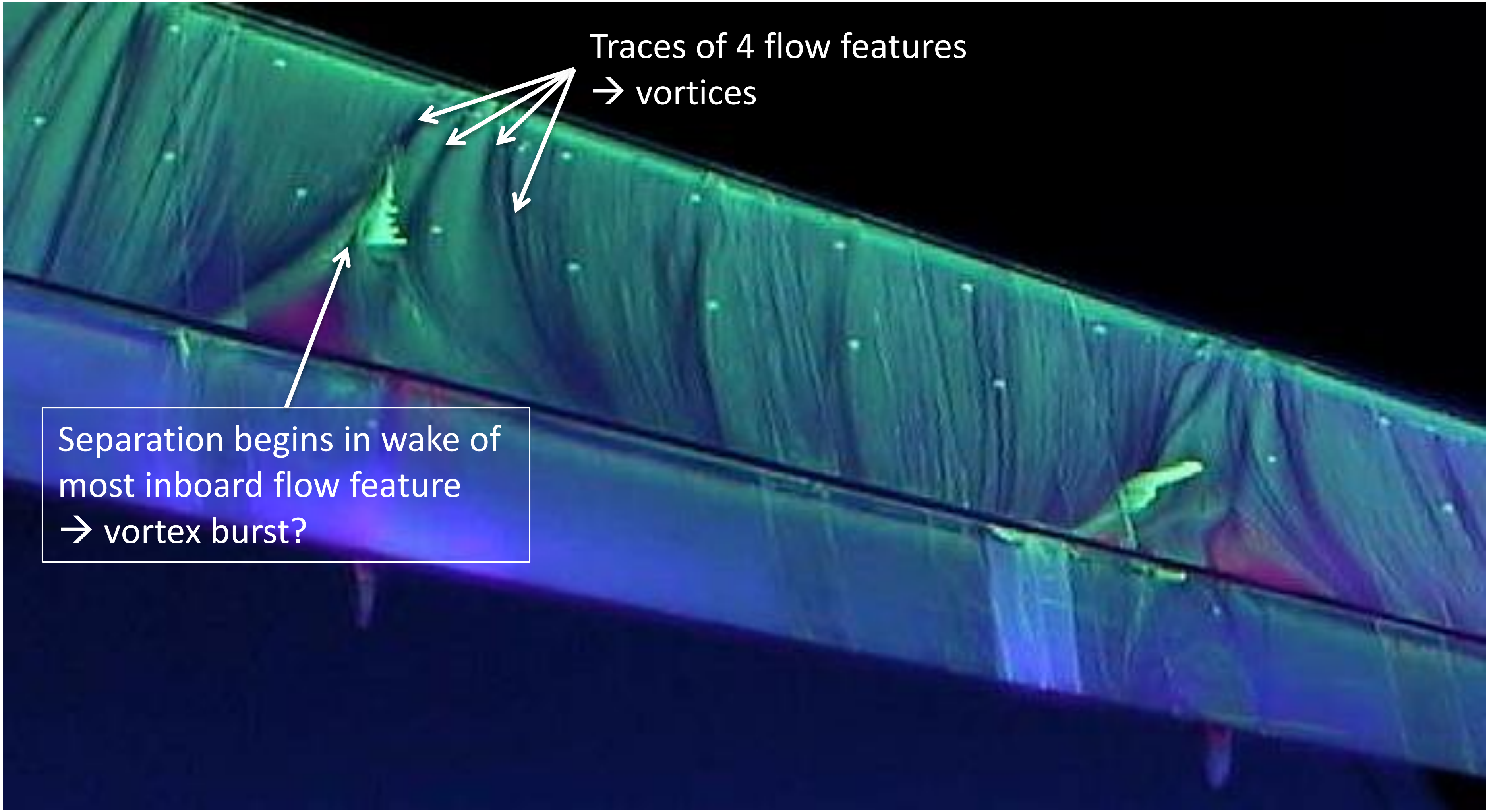
→Simulation does not capture bundle effect on stall

Full Configuration Study

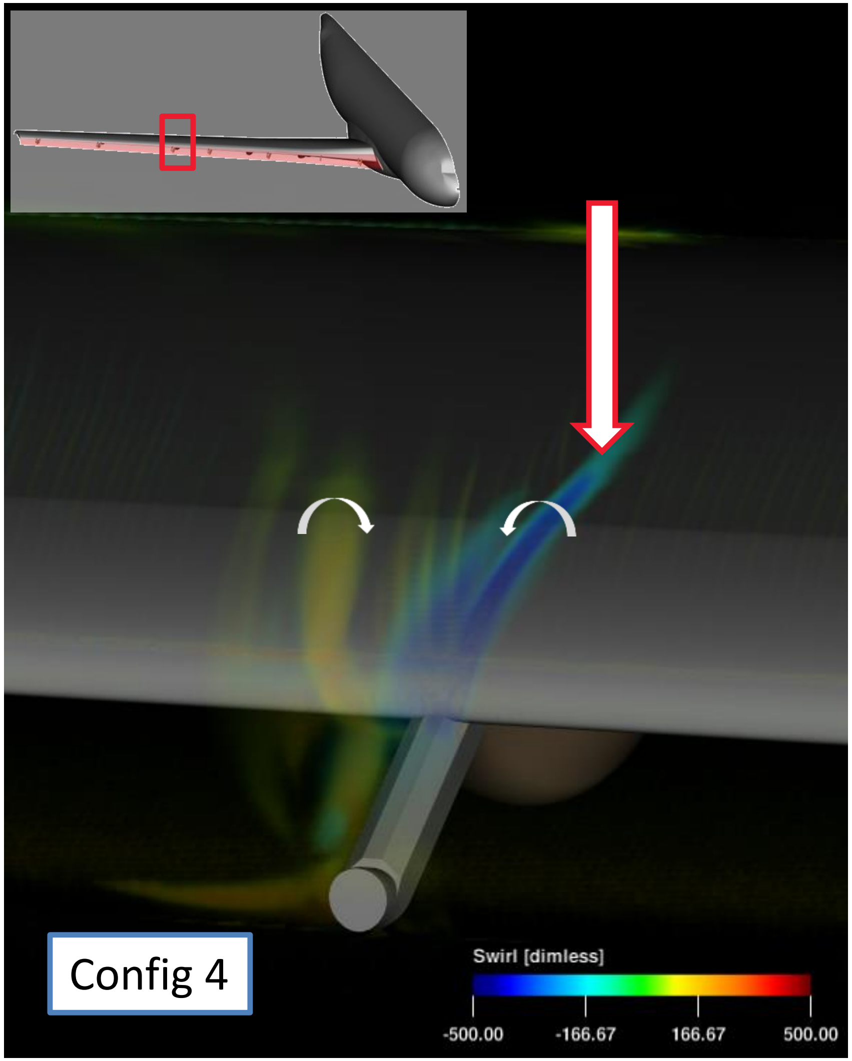
Surface Visualization – Oilflow Flow / Streamlines

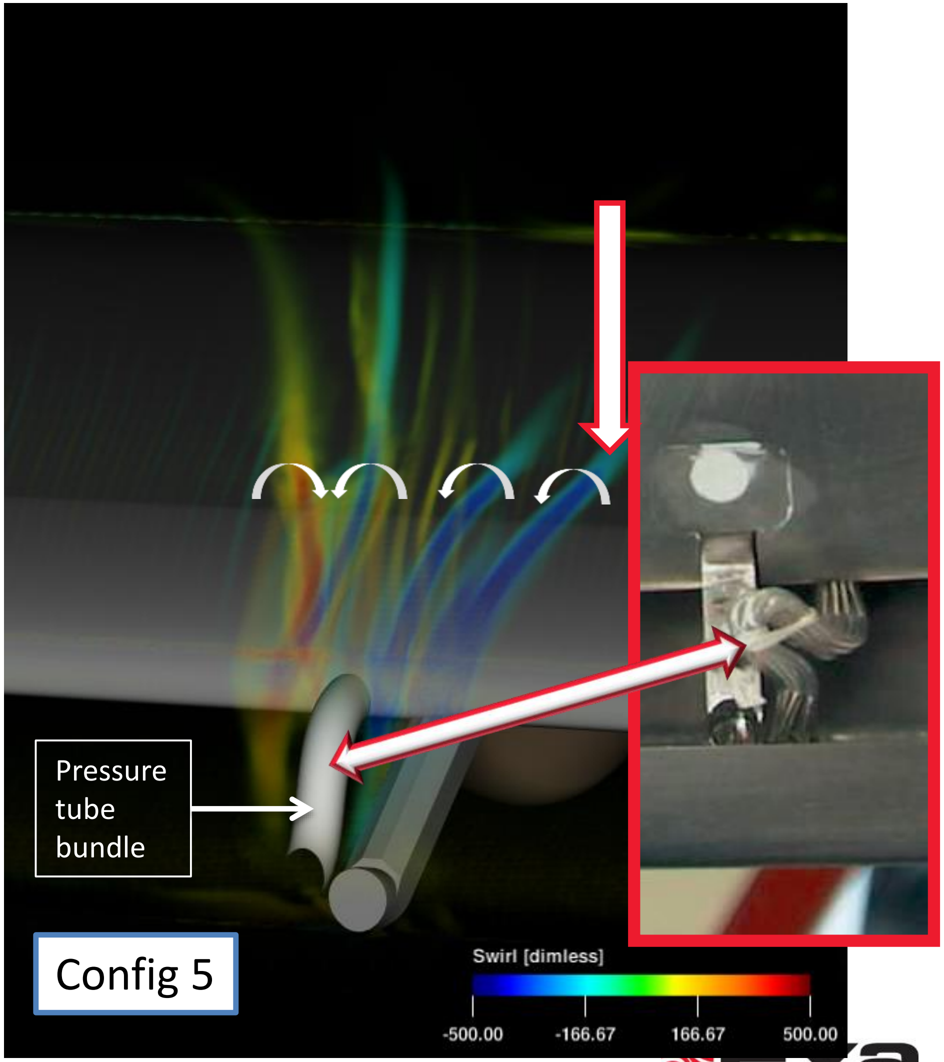


Full Configuration Study
Surface Visualization – Oilflow Detail



Full Configuration Study
Volume Visualization – Swirl





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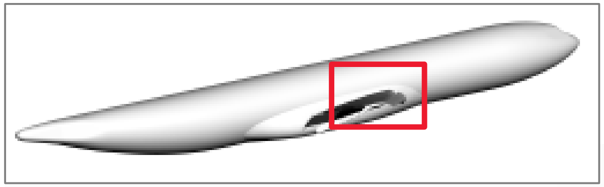
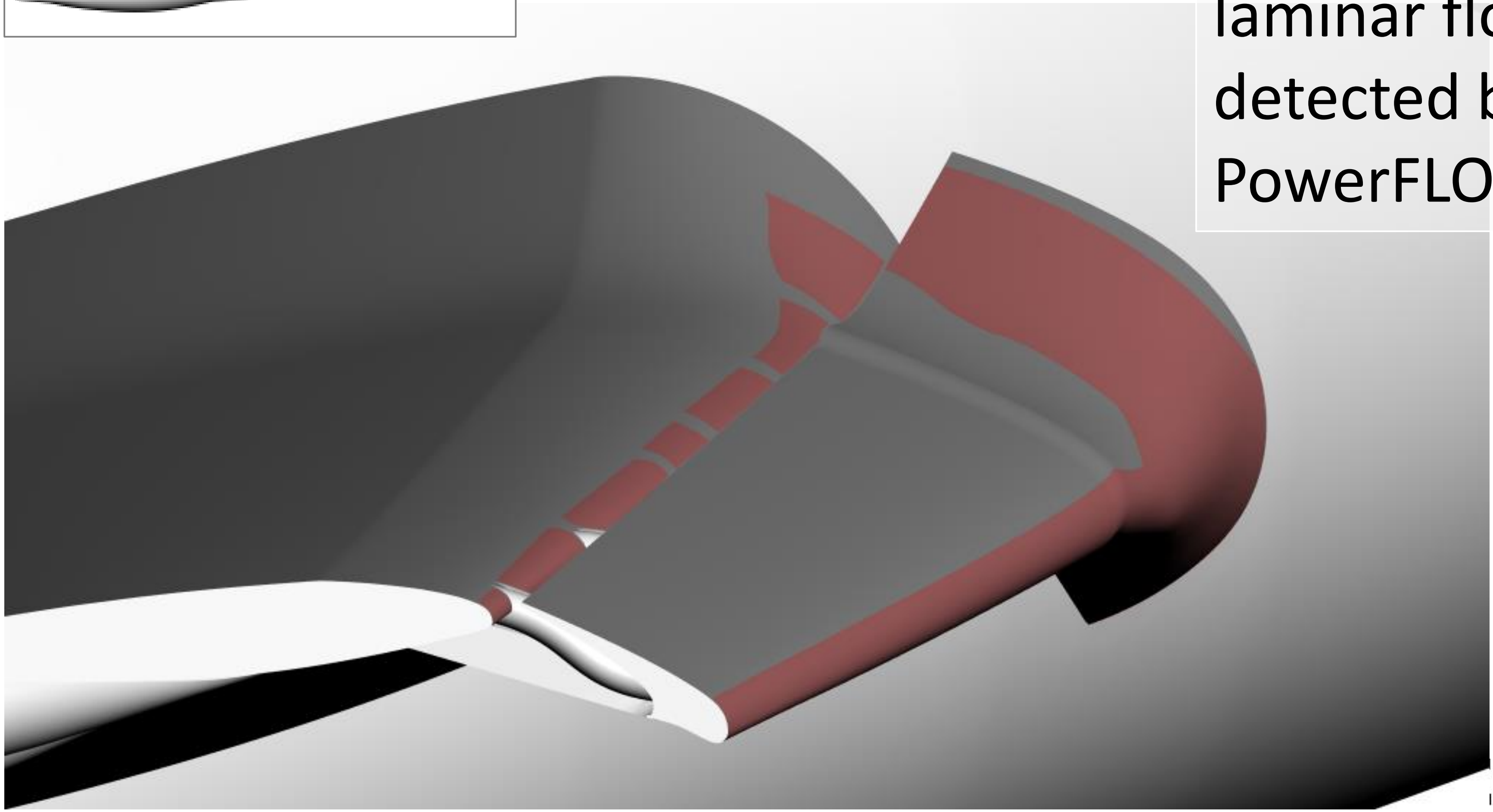
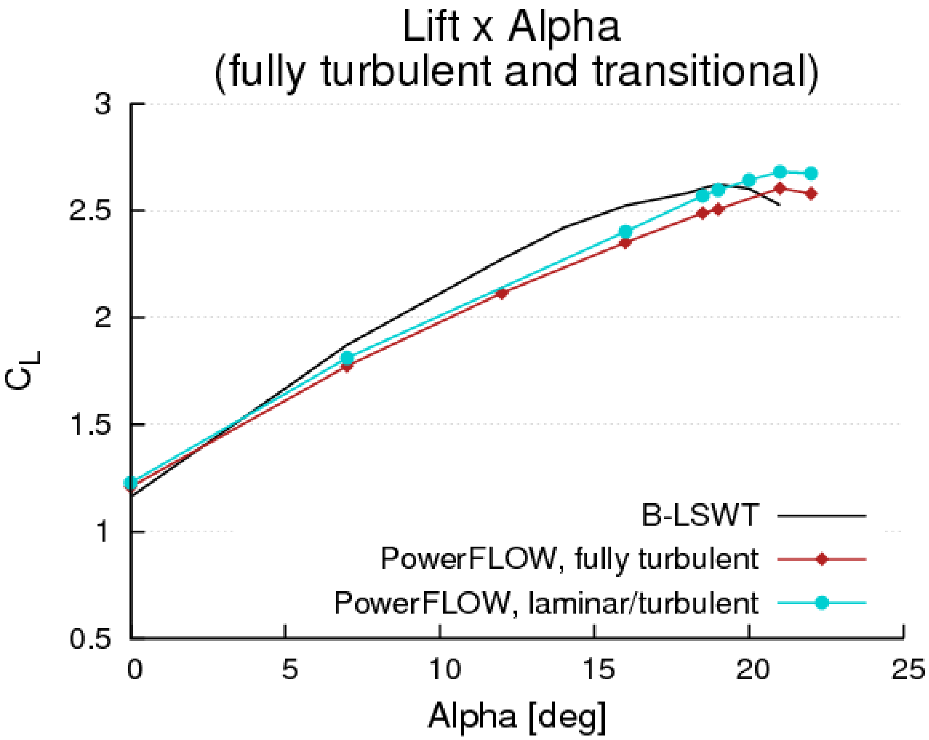
Laminar/Turbulent Transition Study
Laminar Regions Detected

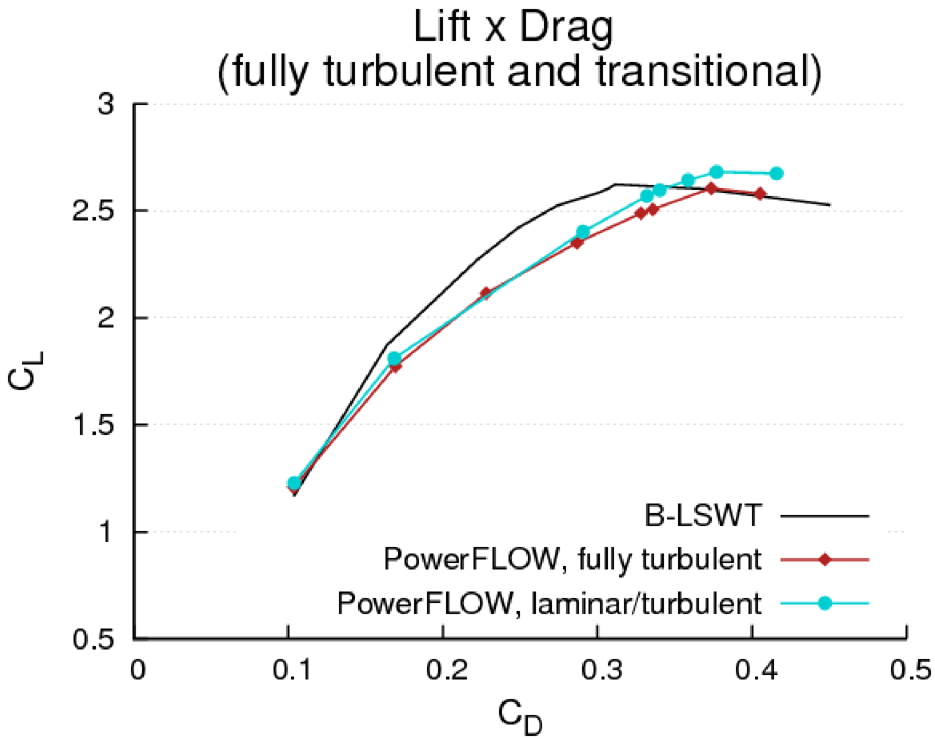




Regions of laminar flow detected by PowerFLOW

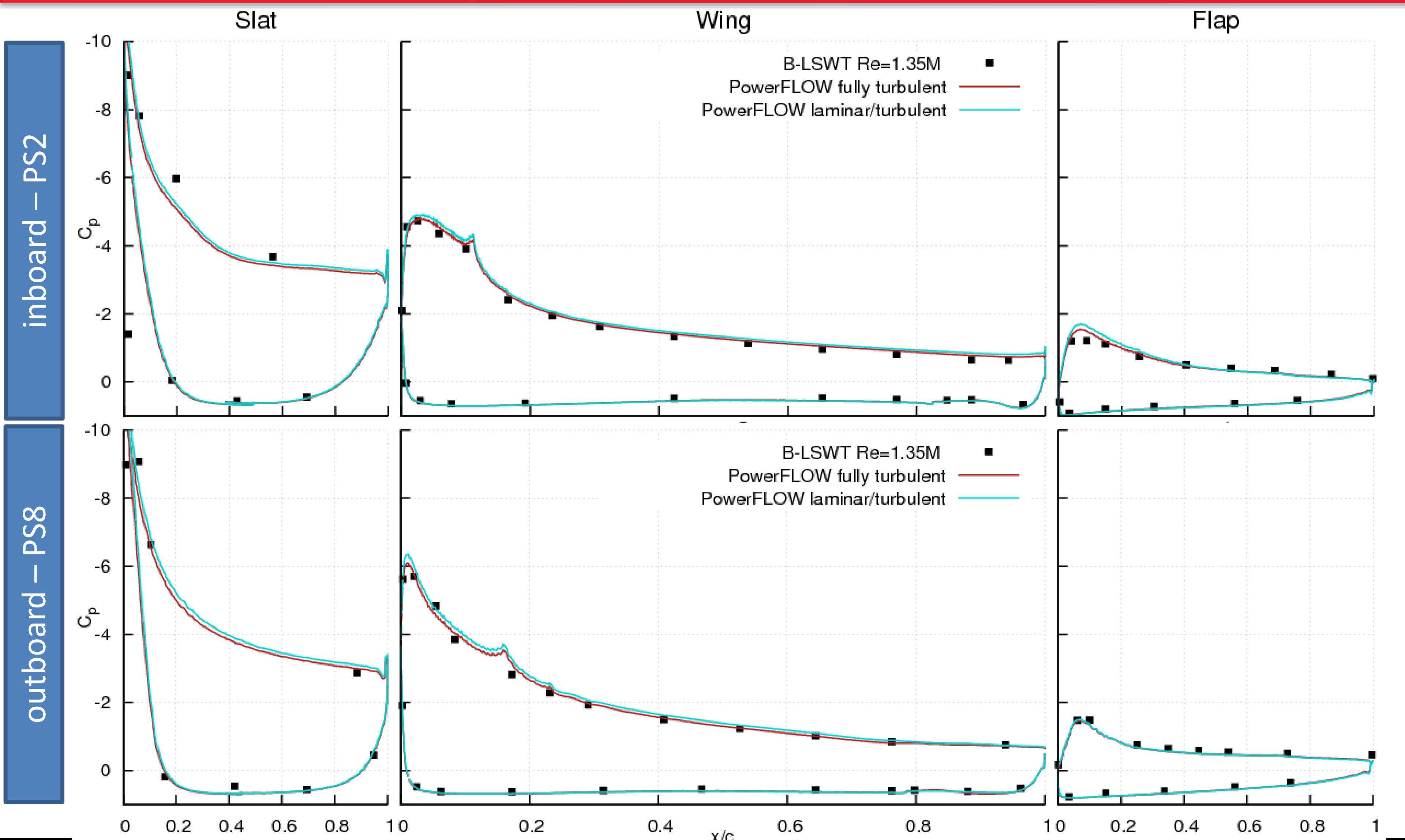
Laminar/Turbulent Transition Study
Lift and Drag Polars





- Lift increase of 7-8 lift counts around $C_{L,max}$
- In line with expectation of non-negligible transition effect

Laminar/Turbulent Transition Study
Pressure Distributions – Alpha = 21deg



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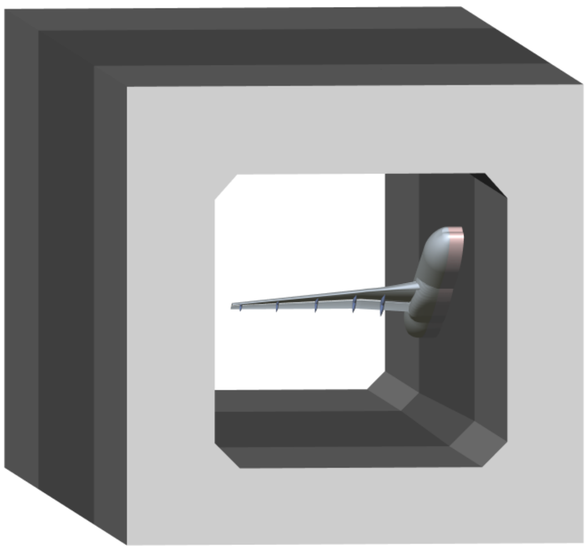
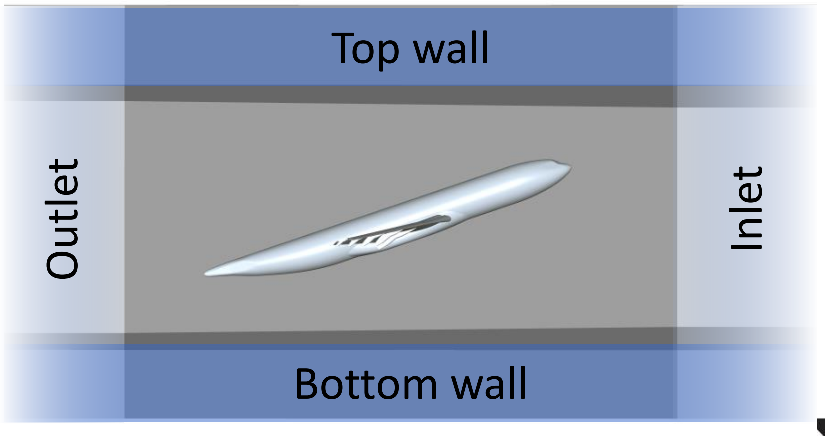
Wind Tunnel Effect Study
Introduction

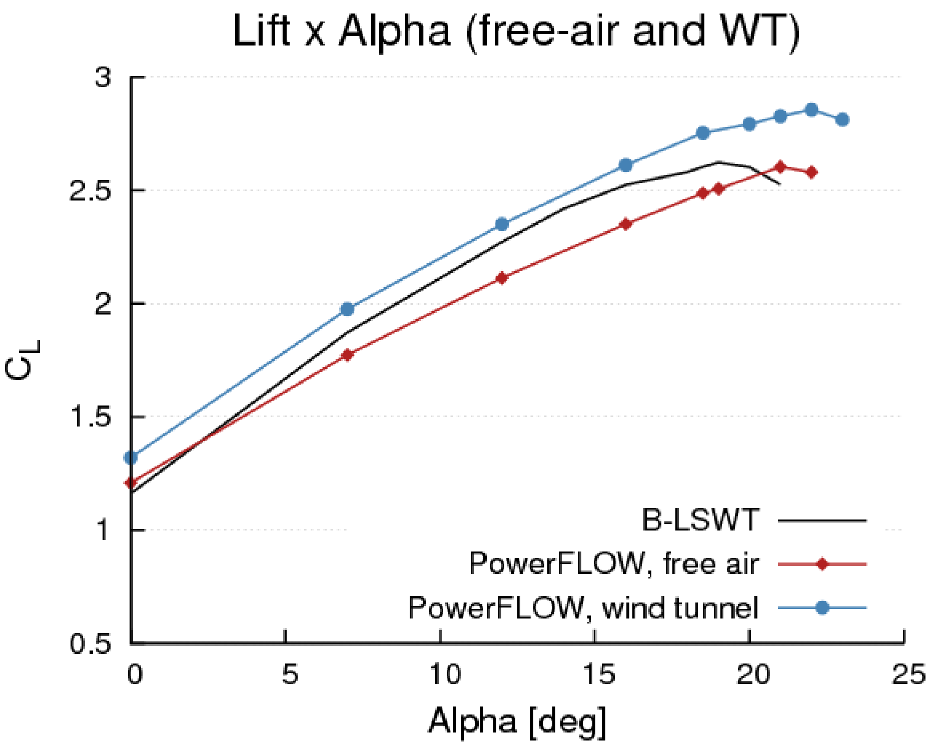
- Generic wind tunnel test section with dimensions similar to B-LSWT
  - *cross section 2.1 x 2.1 m^2*
  - *Test section length 4.45 m*
- Peniche height 100 mm
- Near-field grid similar to previous Low-Reynolds setup
- No official corrections available for wind tunnel simulations

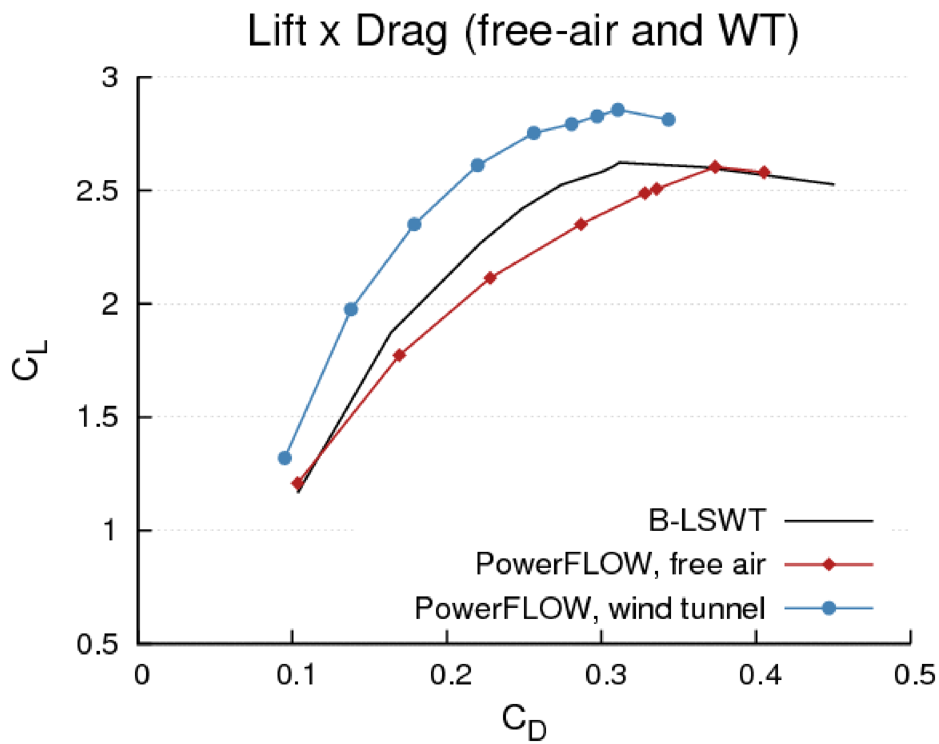




Wind Tunnel Effect Study

Lift and Drag Polars



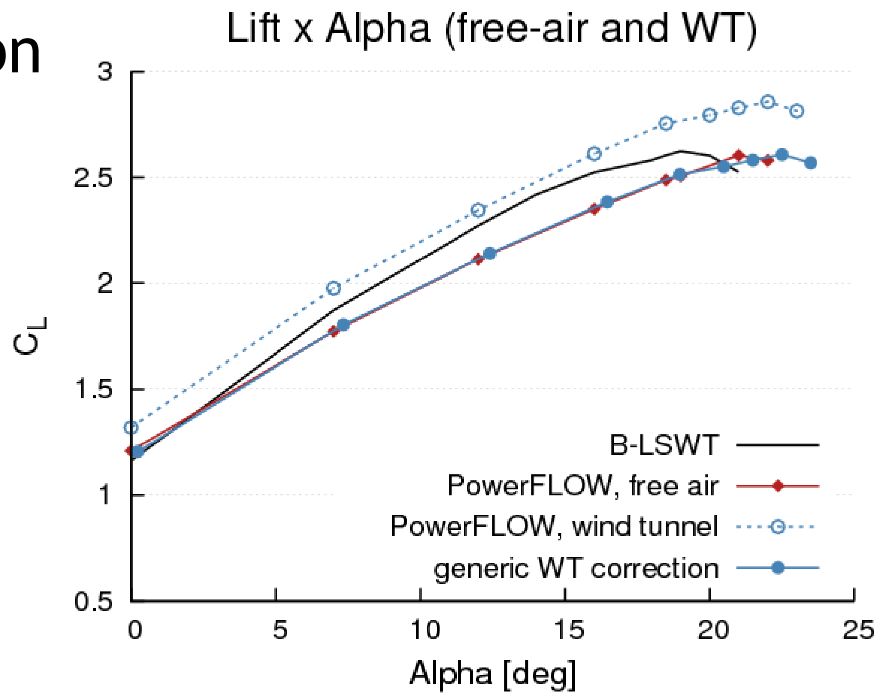


- Uncorrected WT simulation → not directly comparable
- Overall polar shape seems improved

Wind Tunnel Effect Study

Generic Wind Tunnel Corrections

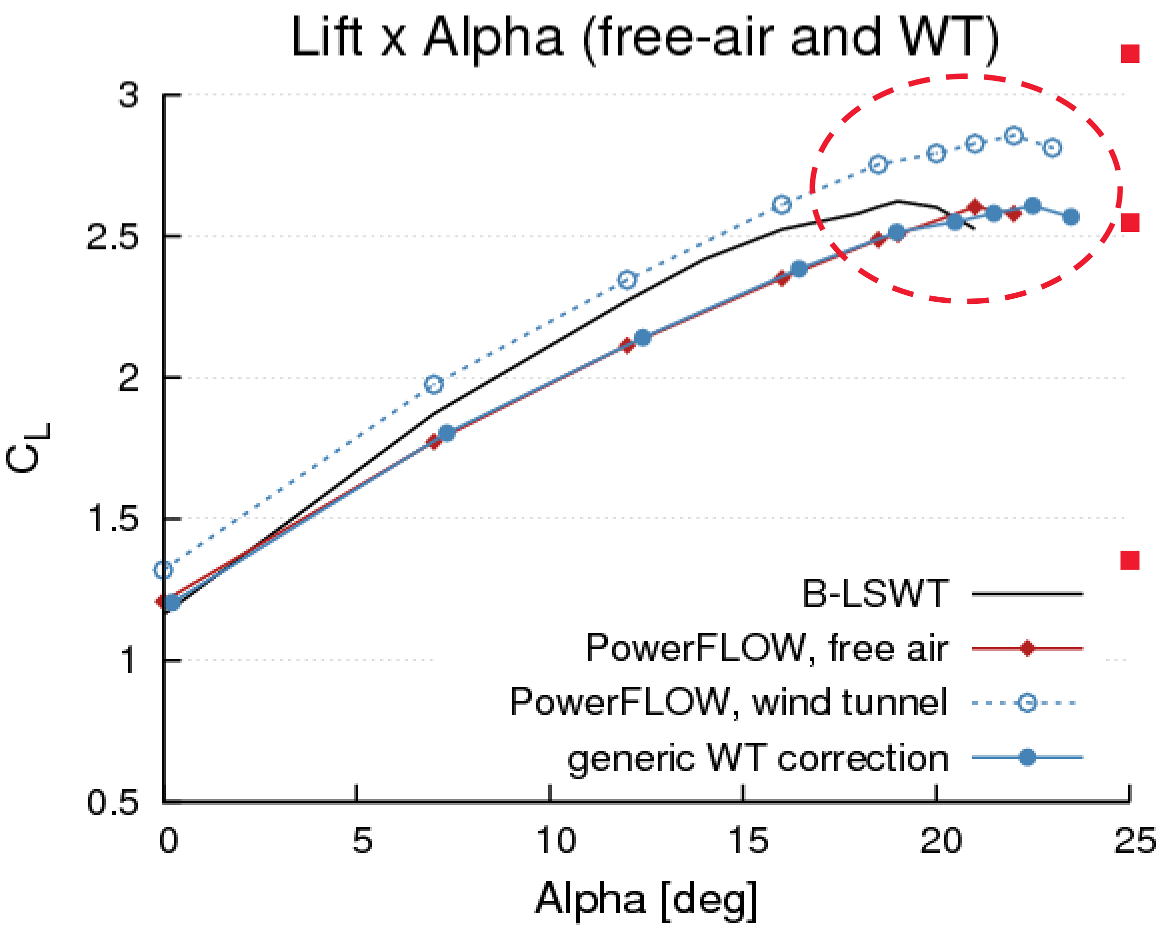
- Generic wind tunnel correction
  - $\Delta\alpha = \delta_\alpha \, C_L$
  - $\Delta C_L = \delta_{CL} \, C_L$
  - $\Delta C_D = \delta_\alpha C_L{}^2$
  - $\Delta C_M = -\frac{\delta_{CL}}{8} C_L$
- Interference parameters δ_α and δ_{CL} chosen to match free-air simulation in linear range



- Goal: free-air and WT simulations corrected to similar standard

- For more details click here
- For a check of the method on the HiLiftPW-1 Trap Wing model click here

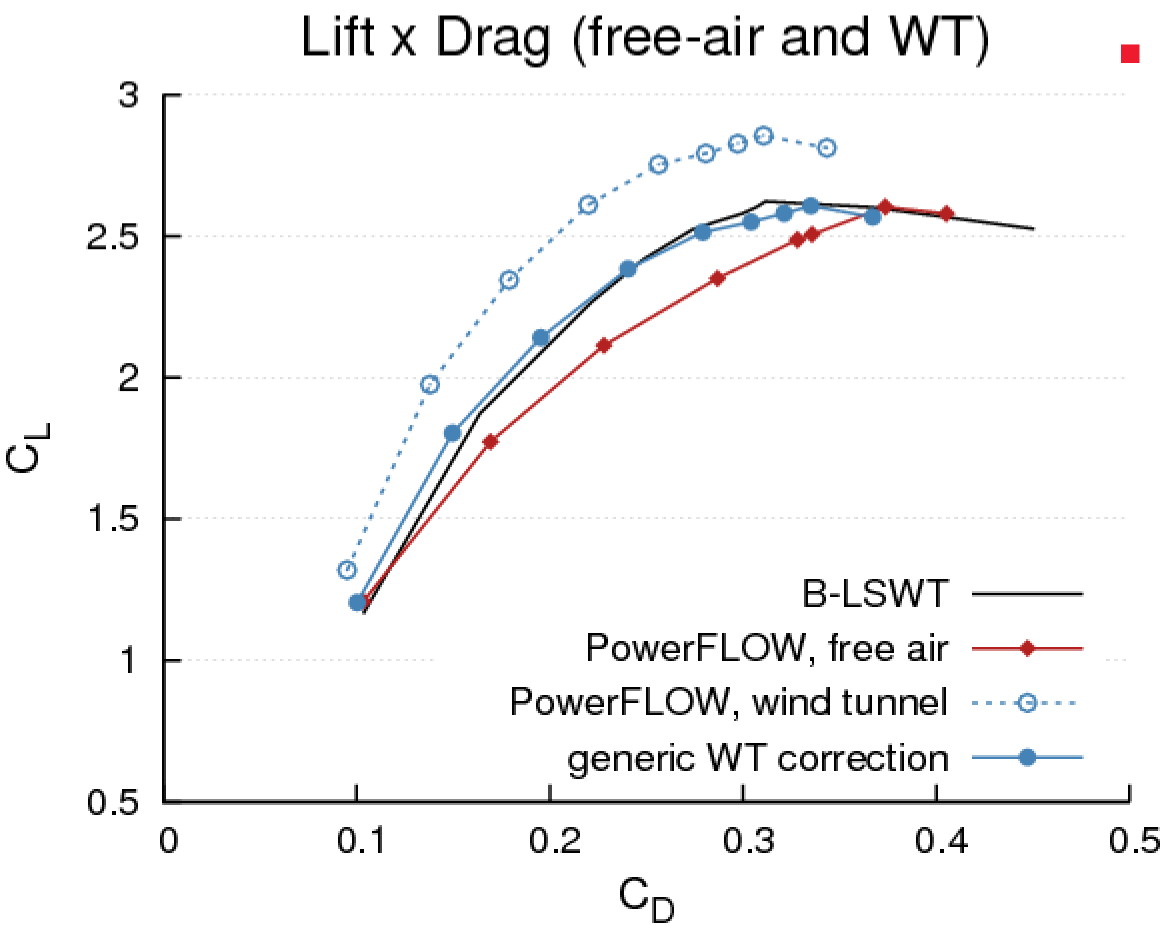
Wind Tunnel Effect Study
Lift Polar – Corrected



- Identical behavior in linear range
- Non-linearity at low C_L slightly captured by WT simulation
- "dip" just before $C_{L,max}$ is captured

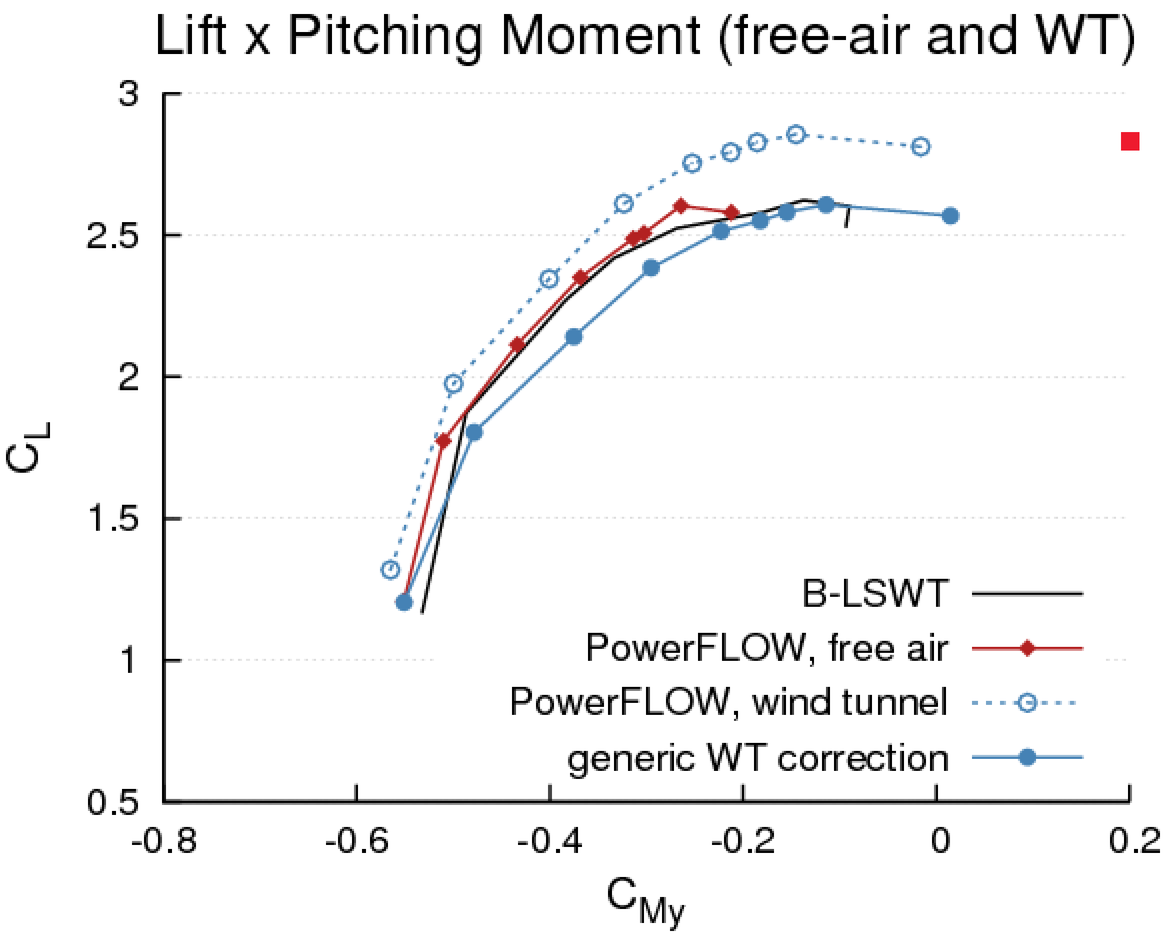
Wind Tunnel Effect Study

Lift x Drag Polar – Corrected



- Nearly perfect match of corrected WT polar

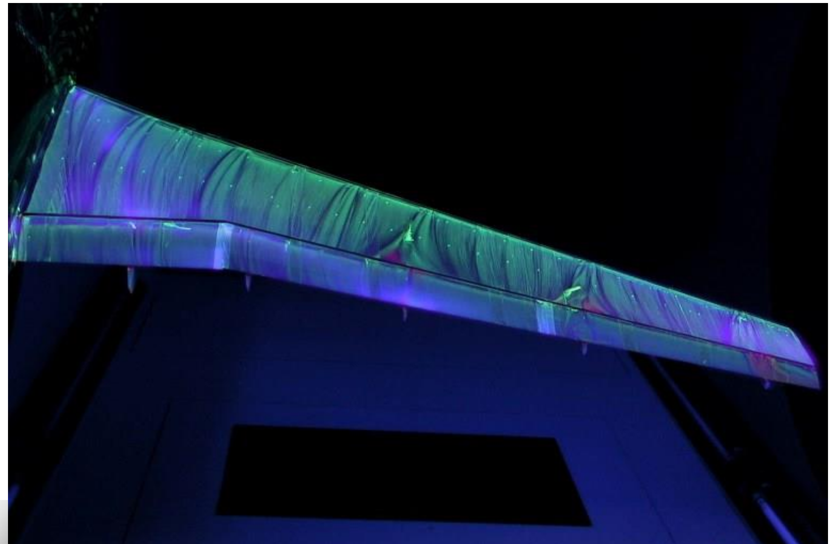
Wind Tunnel Effect Study
Lift x Pitching Moment Polar – Corrected

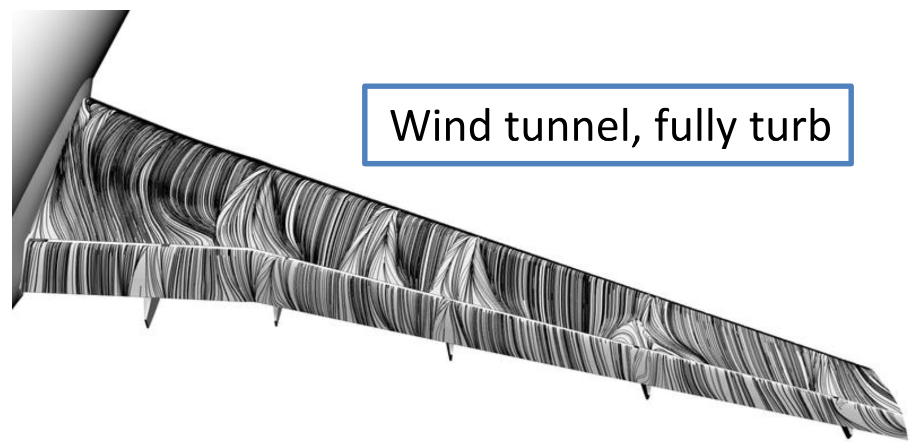


- Good match of both corrected WT and free-air polars

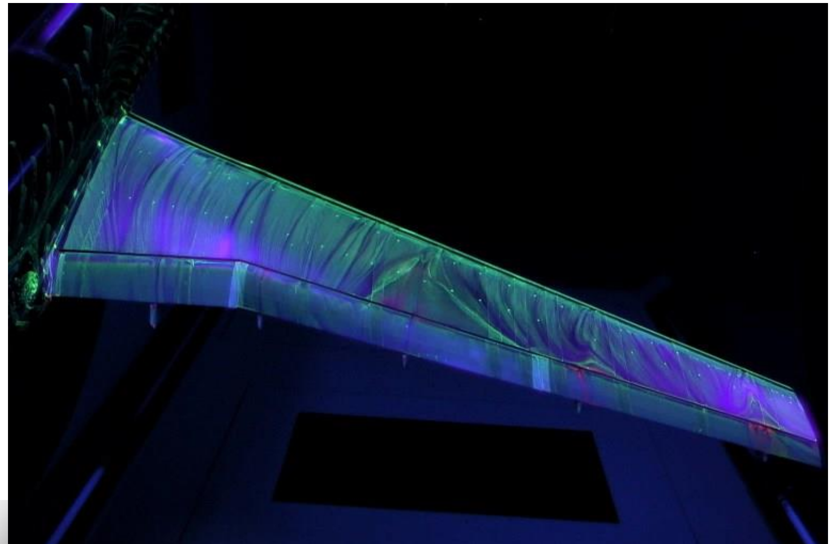
Oilflow / Streamline Visualizations

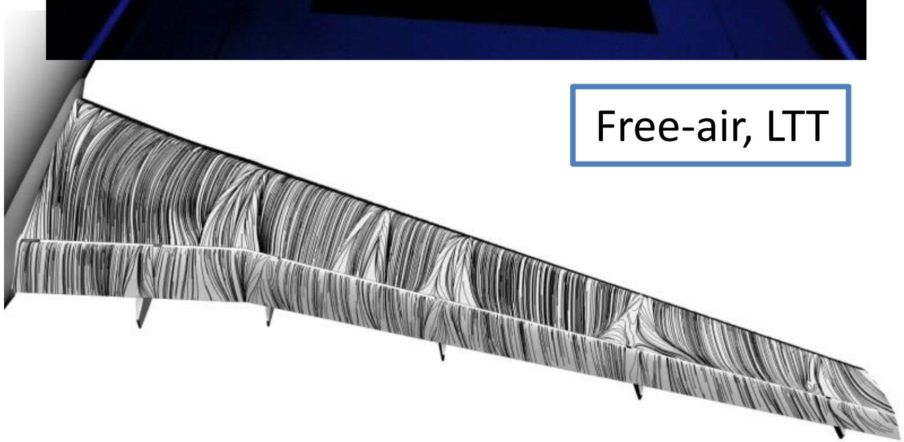
18.5deg

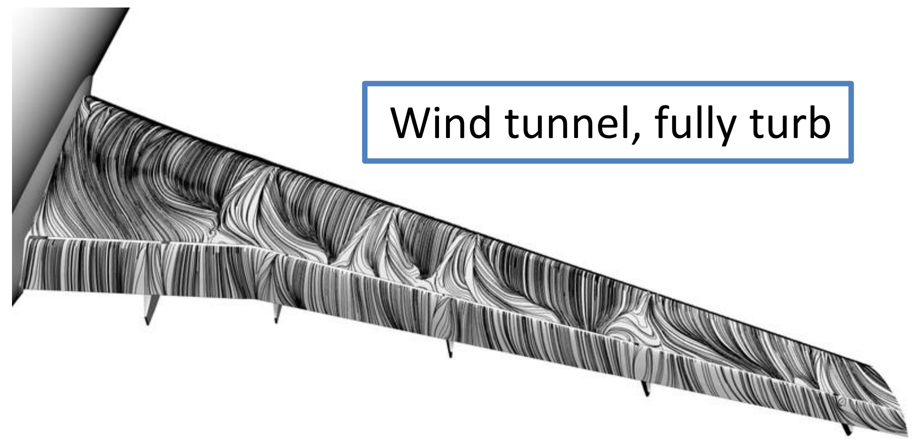




Oilflow / Streamline Visualizations
21deg







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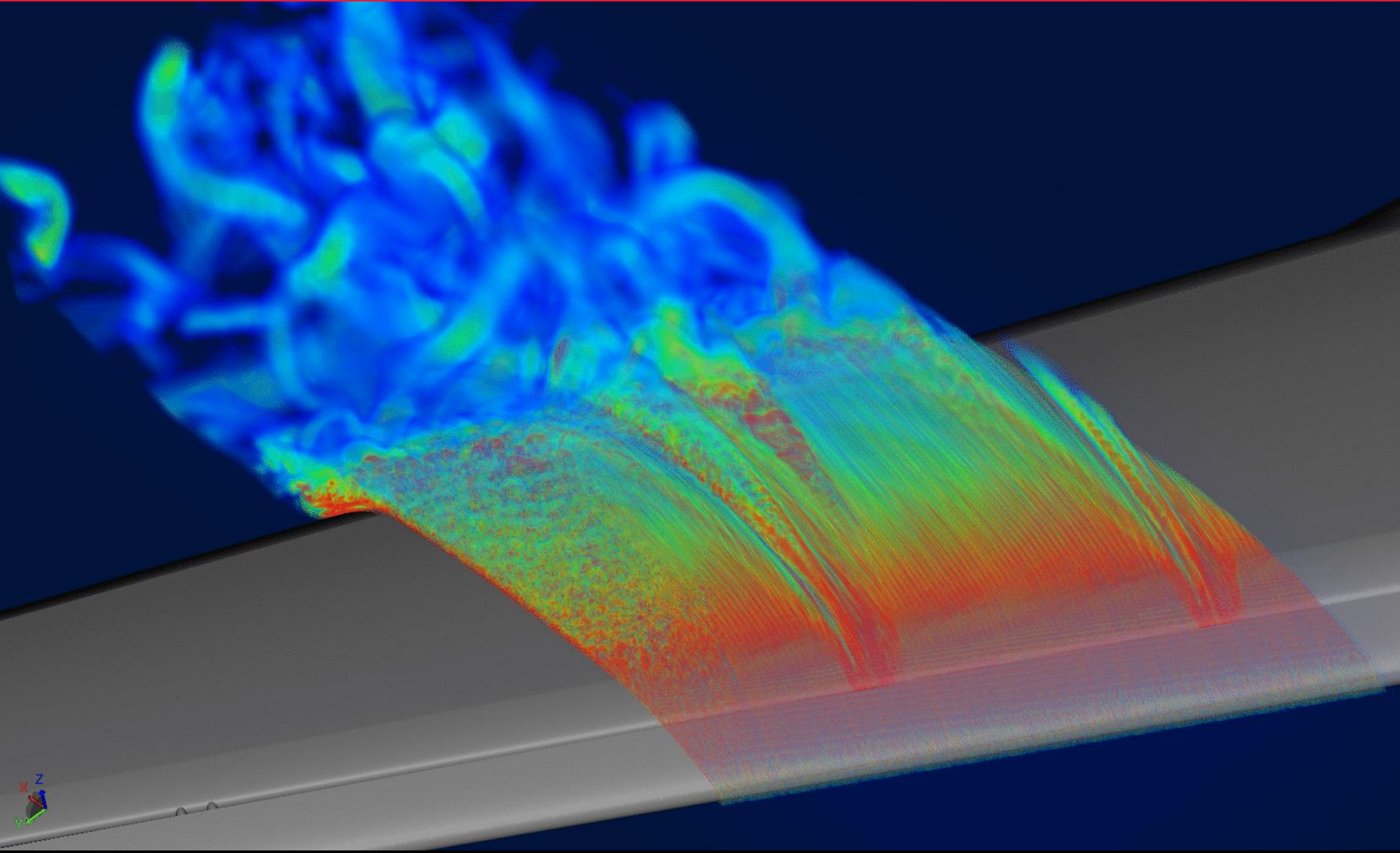
Summary

- $C_{L,max}$ levels well matched
- Good agreement on Reynolds number effects
- Missed correct stall mechanism
- Laminar/turbulent transition shows significant effect on $C_{L,max}$ at low Reynolds number
- Simulation of wind tunnel
  - *Requires appropriate corrections for final conclusions*

Conclusions/Next steps

- Good $C_{L,max}$-prediction of fully-turbulent free-air simulations could be due to compensation of errors
  - *Main flow separation not captured*
  - *Laminar flow not accounted for*
  - *Wind tunnel effects on maximum lift unclear*
- Need to fully understand and capture the stall mechanism
  - *Further investigations of tube bundles geometry shape*
- Need to check wind tunnel corrections or include wind tunnel in simulations
- Include transitional predictions in WT simulations

Thank you!



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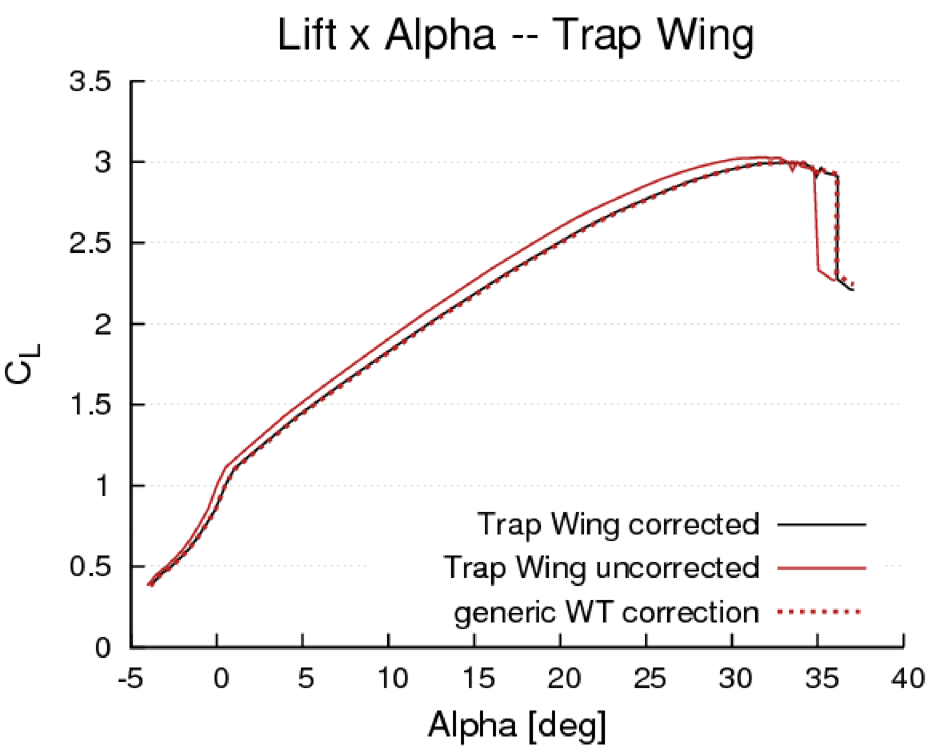
- Appendix: Generic Wind Tunnel Correction

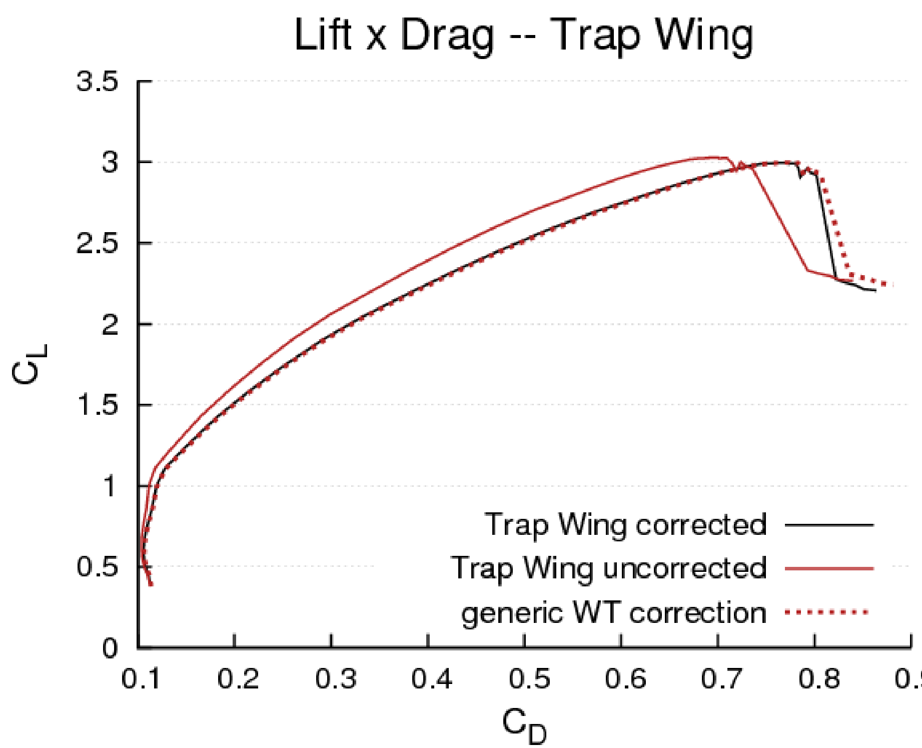
Exa

Appendix – Generic WT Corrections
Derivation

- based on lifting line (AGARD-AG-109, p. 101)
- Angle of Attack
  - $\Delta\alpha = \boxed{\delta_0 \frac{S}{C}} C_L = \boxed{\delta_\alpha} C_L$
- Lift
  - $\Delta C_L = \boxed{-\delta_1 \frac{\bar{c}}{2\beta h} \frac{S}{C} \frac{\partial C_L}{\partial \alpha}} C_L = \boxed{\delta_{CL}} C_L$
- Drag
  - $\Delta C_D = \boxed{\delta_0 \frac{S}{C}} {C_L}^2 = \boxed{\delta_\alpha} {C_L}^2$
- Pitching Moment
  - $\Delta C_M = \boxed{\delta_1 \frac{\bar{c}}{16\beta h} \frac{S}{C} \frac{\partial C_L}{\partial \alpha}} C_L = \boxed{-\frac{\delta_{CL}}{8}} C_L$

Appendix – Generic WT Corrections
Applied to Trap Wing





- Generic Correction based on structure given
  - *AGARD-AG-109 (Subsonic Wind Tunnel Wall Corrections)*
  - *AGARD-AG-336 (Wind Tunnel Wall Correction)*
- Interference parameters for AoA and lift chosen to reproduce the corrected data